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Performance evaluation and engineering considerations for a modular- and culvert-based paddlewheel circulator for split-pond systems

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ABSTRACT

The split-pond system (SPS) has been proposed as an alternative culture method to increase the efficiency of pond aquaculture production. This study evaluated the performance and the engineering models of paddlewheel circulators on commercial catfish SPSs.

The power requirement and the water flow rate by the circulators increased as the rotational speed and water depth in the culvert increased. The rotational speed increased the power requirement exponentially and the water flow rate linearly, while the water depth, which determined the wetted surface area of paddles, increased both linearly. Increasing the rotational speed decreased relative pumping efficiency relative to power used. Under the given field operational conditions, the predicted power requirement appropriately corresponded with the measured power requirement and the predicted values were within 95% of measured values. Good agreement was also noted between measured and predicted water flow rates, and the predicted values were 91.4% of the measured values.

Based on the models developed, it was projected that increasing the wetted surface area of paddles is more energy efficient than increasing the rotational speed and minimizes mechanical failure due to high torque. However, the power requirement was also projected to increase with increasing wetted surface area at a certain threshold, as attempts to decrease the rotational speed were made to achieve a target water flow rate.

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1. Introduction

Since traditional earthen ponds have been devoted to aquaculture production, channel catfish (*Ictalurus punctatus*) has accounted for the largest portion of US aquaculture production (Kaliba et al., 2007). Since the early 1970s, efforts to intensify pond aquaculture have enhanced productivity of pond culture and sustained its business feasibility (McDonnell, 2012). In the US, rising production costs and competition with foreign countries have negatively impacted business revenues and total water surface area for production has declined substantially since 2008 (USDA, 2012). As a result of these challenges, demand for innovations to improve production efficiency in pond aquaculture has increased (Bastola and Engle, 2012).

To increase the efficiency of pond aquaculture, the split-pond system (SPS) has been proposed as a solution to the limitations of oxygen supplementation and waste treatment in static ponds (McDonnell, 2012). The SPS was originally designed by researchers at Mississippi State University (Tucker and Kingsbury, 2010) by drawing from advantages of the partitioned aquaculture system (PAS) of Clemson University. The PAS is reported to enhance catfish production by 4–6 times compared to conventional earthen ponds (Brune et al., 2004, 2012). Currently, there are over 550 ha of split-pond production systems in Mississippi, Arkansas, and Alabama devoted exclusively to catfish culture, primarily hybrid catfish (Travis Brown, United States Department of Agriculture Agricultural Research Service, Stoneville, MS, personal communication). With the success experienced by many farmers utilizing the SPS it is gaining popularity and more traditional ponds are being modified into SPS.

The SPS consists of two uneven sections divided by an earthen levee, and confines fish in a small section that comprises 15–20% of the total pond area. The remaining area (80–85% of the total pond area) serves as a large algal growth basin that provides oxygen production and waste treatment. These two pond sections are connected by two water pathways, and water between the two

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sections is actively circulated by a circulator when oxygen levels are adequate. Water exits the fish basin through one pathway and flows back to the fish basin by the circulator through the other pathway, following a residence time in the algal basin. During the daytime, water is exchanged to remove wastes and replenish oxygen in the fish basin through the algal basin. Circulation is stopped at night, and paddlewheel aerators are run to supply oxygen only into the fish basin. Confinement of fish to the small basin allows for efficient aeration compared to traditional ponds. It also allows farmers to feed and harvest fish more efficiently, increasing production and revenues.

Due to a relatively modest construction investment, convenience in retrofitting existing earthen ponds and ease of operation (McDonnell, 2012), the SPS is being recognized by commercial catfish farmers as an alternative culture method to maximize production of fish while allowing for better culture management in ponds. McDonnell (2012) has evaluated the performance of a SPS and provided a better understanding of water quality and nutrient dynamics in the SPS. Brown and Tucker (2013) provided practical understanding in designing a slow turning paddlewheel circulator. Currently, there is still little information available regarding the performance efficiency of paddlewheel type circulators. The primary benefits of the SPS compared to traditional earthen ponds are from water circulation and mixing. Most circulators developed have been designed with insufficient engineering information and the performance of circulators in SPS has not been examined systematically in applied field trials on commercial fish farms. The performance and efficiency of circulators varies according to operational parameters such as rotational speed, and submergence depth of paddles (wetted surface area of paddles). Optimizing the terms of power consumption and water flow rate would minimize the energy cost of pond circulation and mechanical failure and maximize water pumping efficiency. The paddlewheel circulator used in this study was designed in the fashion of a modular and culvert-based paddlewheel circulator. This particular model is easy to transport, assemble, and install. It also minimizes construction investment compared to an oversized paddlewheel circulator and supporting structures. The objectives of this study were: (1) to gather performance information of the modular- and culvert based paddlewheel circulators installed on commercial farms, and (2) to establish engineering models and design considerations for further refinement and optimization of the paddlewheel type circulators.

2. Materials and methods

2.1. Dimensions and manufacture of the paddlewheel circulator

The circulator had eight paddles, consisting of seven wooden blades each (Fig. 1). The wooden blades were fastened to galvanized square tubing (5.08 cm) and designed to be bolted to a central hub to allow for easy field installation. A solid keyed shaft (6.19 cm in diameter) was coupled to the center of the central hub with SF series bushings and weld-on hubs. Seven wooden blades (1.52 m long × 15.2 cm wide × 2.54 cm thick) were placed over the edge of each paddle, covering the width of paddle. In order to reinforce the paddle and overcome the drag force that results from the rotating motion of the paddle through the water, struts were bolted between the paddles on both sides of the paddle frames. The paddlewheel circulators were equipped with either a 5-hp or a 7.5-hp AC electric motor (three-phase and 480 V) with a rotational speed of 1750 rpm. The 5 hp motors were connected to a gear box (model # 305L3 220NPC N210TC, Bonfiglioli, Hebron, KY) that directly reduced the shaft rotational speed to 7.8 rpm. The 7.5 hp units were connected to a gear box (model # 306L3 228NPC N210TC, Bonfiglioli, Hebron, KY) resulting in a reduced rotational speed of 7.35 rpm.

Fig. 1. The modular- and culvert based paddlewheel water circulator used in commercial split-pond systems.

A variable frequency drive was installed to allow for further control of paddlewheel rotational speed.

Two corrugated galvanized metal culverts (1.52 m diameter, 7.62 cm pitch × 2.54 cm rise, and spiral corrugation) were installed through a levee dividing each pond into two sections (20% fish basin; 80% water treatment basin, Fig. 2). A culvert (6.1 m in length) was attached to the paddlewheel device and the other culvert (9.1 m in length) was used for the return water flow. PVC coated wire mesh fish barriers were installed to prevent the escape of fish from both inflow and outflow culverts of the fish basin. Two units were equipped with rectangular mesh (1.27 cm × 2.54 cm) and the remaining units were equipped with square mesh (1.91 cm × 1.91 cm).

2.2. Data collection

Intensive field data was collected from 12 SPSs (1.8–.5 ha SPSs) on two commercial catfish farms in Arkansas. A total of 70 measurements were obtained during the production period from July, 2012 to July, 2013. Due to the difficulty of testing different rotational speeds and submergence depths of the paddle *in situ* on commercial farms, data was collected as natural changes of water depth and rotational speed of the paddle occurred during the ordinary management regimes of each farm.

2.2.1. Power consumption and water flow measurement

The power requirement of circulators was calculated by measuring amperage with a digital ammeter (ACD-10PLUS, Amprobe, Everett, WA) and the following equation for a 3 phase motor.

$$P_m = \sqrt{3} \times PF \times I \times V/1000 \quad (1)$$

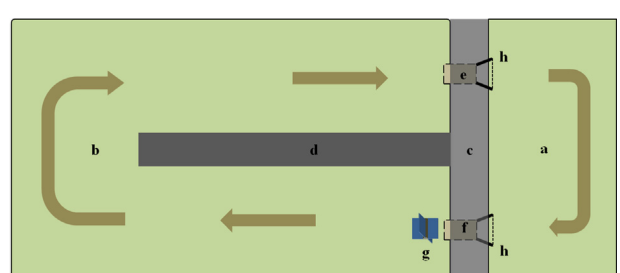

Fig. 2. The schematic diagram of split-pond systems ((a) fish basin, (b) water treatment basin, (c) and (d) earthen levee, (e) and (f) spiral underground culverts, (g) paddlewheel circulator, (h) wing walls and metal screens; arrows indicate the direction of water flow).

where, P_m: power consumption measured (kW), PF: power factor (0.93), I: average amperage (A), V: volts, 1000: conversion constant.

Water flow rate was calculated by measuring water velocity in a culvert using a current velocity meter (Model 3000, Swoffer, Seattle, WA) and the following equation. A 20-cm diameter hole was drilled on the top of the inflow culvert 1.0 m from the exit and a 30-cm long metal standpipe was installed vertically through the ground to facilitate water velocity measurement. Water velocity was measured at 60% of depth from the water surface along the centerline of the culvert.

$$Q = v_w A_c \tag{2}$$

where, Q: water flow (m^3/s), v_w: mean water velocity (m/s), A_c: wetted area of cross section in the culvert (m^2).

The wetted areas of cross section in the round culvert were calculated by the following equations:

$$\alpha = 2\cos^{-1}\left[1 - 2\left(\frac{H}{D}\right)\right] \tag{3}$$

$$A_c = \frac{D^2}{8}(\alpha - \cos\alpha) \tag{4}$$

where, α: the center angle formed with two points which water surface meets on the culvert wall in cross-section, H: water height in culvert, D: diameter of culvert.

2.3. Model development

2.3.1. Power required for a paddlewheel circulator

The paddlewheel type circulator consists of a number of paddles with blades at different radial distances from the center of the wheel. Each paddle surface was oriented perpendicular to the direction of its motion. When a paddle travels through the water column at a certain velocity, a drag force is induced by the motion. This force must be overcome by the torque on the shaft of the wheel, resulting in power consumption. The extent of the torque may vary according to operational parameters, such as paddle rotational speed, projected area of paddles in water, and numbers of paddles and blades. The drag force equation is an empirical formula used to calculate the drag force induced by an object moving through a fluid.

$$F_D = C_D \frac{\rho_w}{2} v_b^2 A_b \tag{5}$$

where, F_D: drag force due to the motion of blade (N), C_D: maximum drag coefficient for blade (dimensionless), ρ_w: mass density of water (kg/m^3), v_b: velocity of blade (m/s), A_b: wetted area of blade (m^2).

The power (P_b, Nm/s) required by the blade due to the drag force can be derived by multiplying the drag force by the blade velocity (Camp, 1955).

$$P_b = C_D \frac{\rho_w}{2} v_b^3 A_b \tag{6}$$

Since the blade is rotating with rotational velocity, ω (rad/s), the velocity of the blade can be expressed as $v_b = \omega\, r_b$, in which r_b is the radial distance (m) to the blade.

$$P_b = C_D \frac{\rho_w}{2} \omega^3 r_b^3 A_b \tag{7}$$

The paddlewheel circulator consists of multiple paddles and blades on a wheel. At a maximum force position of paddles, multiple paddles with multiple blades on a paddle are introduced in the water and the yaw angle of each paddle is different. Drag coefficients for a range of the paddles held static at a range of angles of attack should be trigonometrically calibrated (Sumner et al., 2003) and the power expended by all blades (P_p, Nm/s) on a paddle will be rearranged:

$$C_a = C_D \cos\theta \tag{8}$$

$$P_p = C_D \cos\theta \frac{\rho_w}{2} \sum_1^{n_b} r_b^3 A_b \tag{9}$$

where, C_a: drag force coefficient at an angle of paddle attack, θ, of zero degree, or when the paddle is perpendicular to the direction of water flow, n_b: number of blades.

As a paddle passes through the water column and generates water flow forward, edge turbulence by the paddle occurs and a certain amount of water is forced behind the paddle, entailing energy loss. The energy loss is mainly determined by a combination of the operational parameters, and can be defined by the slip factor (k). If $v_w = (1-k)v_b$ *and* $v_b = \omega\, r_b$, the power required for the paddlewheel circulator can be established by Eq. (10) (Hendricks, 2005).

$$P_p = C_D \cos\theta \frac{\rho_w}{2} (1-k)^3 \omega^3 \sum_1^{n_b} r_b^3 A_b \tag{10}$$

For development of the engineering model of the paddlewheel circulator, the drag coefficient used in this study was 1.32 for $L/W = 10$, as derived based on Rouse (1946). This study also used the slip factors derived from the equation ($k = 0.074 + 0.007$RPM) by Hendricks (2005).

As multiple paddles are immersed in water, eventually, the total power (P_p, Nm/s) required for a paddlewheel circulator can be calculated by the following equation:

$$P_{\mathrm{sum}} = \sum_1^{n_b} \frac{P_p}{E_g E_m} \tag{11}$$

where, E_g: energy transfer efficiency of gear box (0.4), E_m: energy transfer efficiency of motor (0.85)

2.3.2. Water flow rate by a paddlewheel circulator

Water flow rate generated by rotational force of a paddlewheel circulator can be predicted using a momentum equation that is derived from Newton's second law of motion.

$$F = ma = m\frac{v2 - v1}{t} \tag{12}$$

where, F: force due to the motion of a blade (N), m: mass (kg), a: acceleration (m/s^2), v_1: velocity of mass at time 0 (m/s), v_2: velocity of mass at time t (m/s).

For the control volume, V_w, it is noted that $m = \rho_w V_w$. Since $V_{w/t} = Q$, it can be stated as:

$$F_w = \rho_w Q (v_2 - v_1) \tag{13}$$

where, F_w: momentum due to the motion of water (N), Q: volumetric water flow rate (m^3/s)

Momentum is defined as the product of water mass and velocity of the water mass. For an incompressible fluid, the rate at which momentum is carried across a section is defined mathematically as:

$$F_w = \rho_w Q v_w \tag{14}$$

Assuming that the rotational force of the paddles is transferred to moving the water without energy loss, equation 14 can be rearranged as:

$$F_{Ds} = \rho_w Q_p v_w \tag{15}$$

where, F_{Ds}: sum of drag force by multiple blades and paddles immerged, Q_p: volumetric water flow rate generated by a paddle (m^3/s).

Rearranging Eq. (15), we can also state that:

$$Q_p = \frac{F_{Ds}}{\rho_w v_w} \tag{16}$$

$$Q_p = \frac{F_{Ds}}{\rho_w (1-k) v_b} \tag{17}$$

As water flows through each compartment such as fish and water treatment basins, culverts, and screens in a split pond, energy loss due to friction and dynamic head losses occur. The head losses can be calculated by the following equations:

$$H_f = \left(\frac{nV_w}{1.49R^{2/3}}\right)^2 L \quad (18)$$

$$H_d = K\frac{V_p^2}{2g} \quad (19)$$

$$H_s = \beta \sin\alpha(s)^{4/3} \quad (20)$$

where, H_f: friction head loss through fish and water treatment basins, and culverts (m), n: Manning's roughness coefficients (0.022 for the earthen basins; Chow (1959), and 0.028 for corrugation metal pipes; USGS (1993), V_w: water velocity according to tangential paddle velocity (m/s) in front of paddlewheel circulator, R: hydraulic radius of pond channel and culvert (m; the ratio of the channel's cross-sectional area of the flow to its wetted perimeter), L: length of pond channel and culvert (m), H_d: dynamic head loss by directional change, K: dynamic head loss coefficient (2 for 180 degree bend by Green et al. (1995), and 0.5 for entrance and 1 for exit for culvert), g: gravitation acceleration (9.8 m/s^2), H_s: dynamic head loss by screen (m), β: screen resistant coefficient (2.34 for square mesh), α: screen angle to water flow (90 degrees when the screen is perpendicular to the direction of water flow), s: space between two parallel wires (cm).

Eventually, the water velocity and water flow rate in the inflow culvert to the fish basin can be predicted by Eqs. (21) and (22).

$$V_i = \left(\frac{1}{n}\right) R^{2/3} S^{1/2} \quad (21)$$

$$Q_c = V_i A_c \quad (22)$$

where, V_i: predicted water velocity at a culvert for water inlet to fish basin (m/s), S: the slope of water surface (head loss/channel length), Q_c: corrected water velocity through inlet culvert to fish basin (m^3/s), A_c: wetted cross section area in culvert (m^2).

3. Results and discussion

3.1. Measured water flow rates and power requirements

Under the reported field conditions, the rotational speeds of the circulators ranged between 5.5 and 8.0 rpm, and the water depths in the culvert ranged between 0.94 and 1.42 m. Power expended by circulators increased from 2.91 to 7.85 kW, as paddle rotational speed and water depth increased. The power expended by the circulators increased linearly with increasing water depth, while it increased exponentially with increasing paddle rotational speed (Fig. 3). Water flow rate linearly increased from 41.1 to 87.1 m^3/min, as the paddle rotational speed and water depth increased (Fig. 4). Brown and Tucker (2013) also found a linear relationship between rotational speed (1–4 rpm) and water flow rate at the given water depth of 1.22 m. In their study, the maximum water flow rates of a slow rotational paddlewheel was around 66 m^3/min of water (the values were estimated from the graph) at 4 rpm with the presence of screen fish barriers. The result was comparable with 53.2–66.7 m^3/min under similar operation conditions (5.3–5.5 rpm at 1.22–1.27 m) in this study.

Based on observation of measured power requirement and water flow rate in this study, the rotational speed increased power requirement exponentially and water flow linearly, while water depth, which determines wetted surface area of paddles, increased both power requirement and water flow rate linearly. Increasing rotational speed decreased relative pumping efficiency relative to power used. Fig. 5. indicates water flow rates relative to power

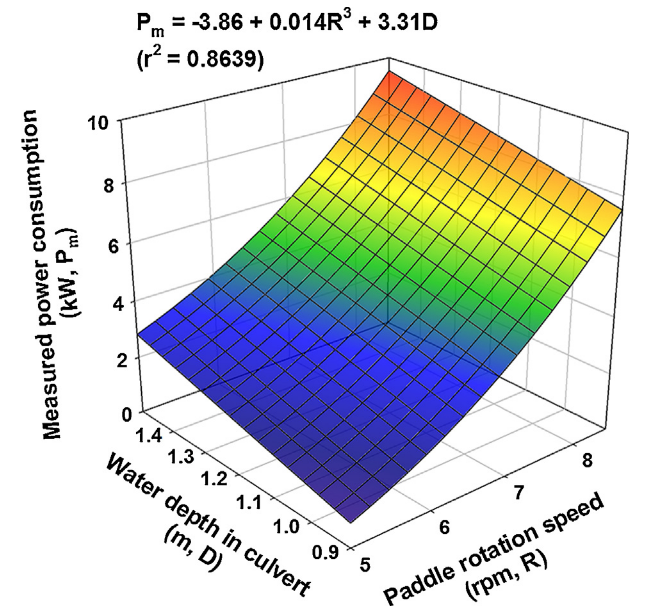

Fig. 3. Power required at different paddle rotational speeds and water depths in the inflow culvert at commercial split-pond systems.

input (18.1–9.8 m^3/min/kw) and confirmed decreasing pumping efficiency with increasing rotational speed, which agreed with Brown and Tucker (2013) with a slow-rotating paddlewheel circulator in a SPS. However, in this study, relative water flow rate slightly increased with increasing wetted surface area of paddles.

3.2. Model development

The power requirements measured from field observations were compared with those predicted by the theoretical models developed in this study (Fig. 6). Under the given field conditions, the predicted power requirements ranged from 2.70 to 7.19 kW. The model appropriately predicts the actual power requirement with an r^2 = 0.8174, and predicted values were 95% of measured values according to the regression line.

Based on features and components of ponds, flow pattern, and operational parameters of circulators, head losses were calculated

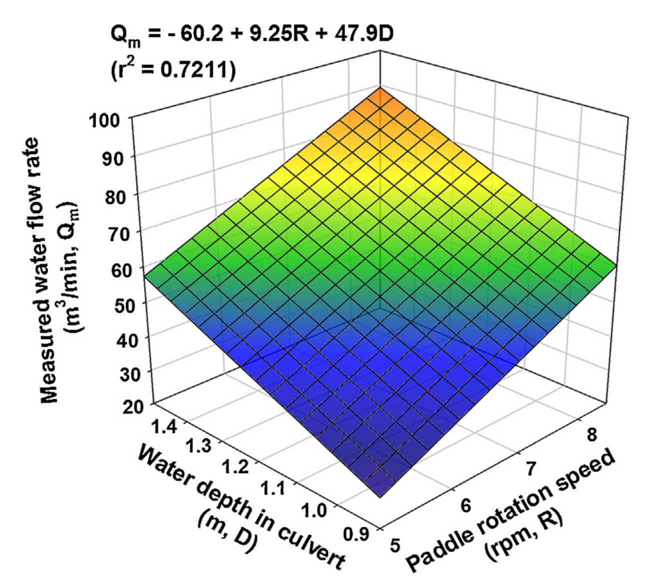

Fig. 4. Water flow rate at different paddle rotational speeds and water depths in the inflow culvert at commercial split-pond systems.

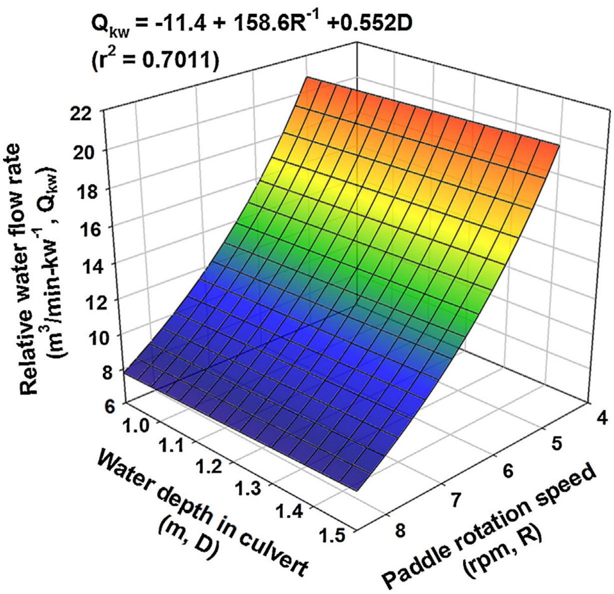

Fig. 5. Relative water flow rate at different paddle rotational speeds and water depths in the inflow culvert at commercial split-pond systems.

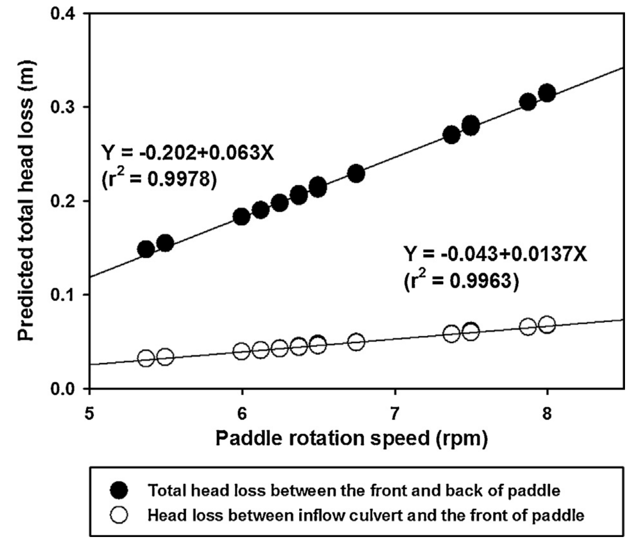

Fig. 7. Predicted head loss at different paddle rotational speeds.

and shown in Fig. 7. Within the reported water depth range, water depth did not appear to significantly affect building head losses. However, head losses were significantly correlated with paddle rotational speed and increased with increasing paddle rotational speed. The head losses built between the front of the circulator and the water velocity measuring point in the inflow culvert ranged from 3.2 to 6.7 cm, whereas those between the front and back of the circulator ranged from 14.8 to 31.5 cm. In total, head loss through the two culverts contributed 94.1%, followed by head losses through screens (4.8%), and water treatment and fish basins (1.0%). The flow model has projected that the culverts in the exiting SPSs observed would be in suboptimal size and head loss significantly increased as water passed through culverts. In order to reduce head losses through the culverts and maximize water flow rate at the given power requirement, the proper design refinement would be required taking into account the size, shape and hydraulic cross section of the culverts.

Based on the slip factor equation (Hendricks, 2005) and Manning's equation, water velocities were predicted and compared with measured water velocities at the measuring point in the inflow culvert (Fig. 8). The predicted water velocities, according to tangential velocity of the paddle, appeared to fit well with the measured water velocities in this study. The tangential speed of the paddle proportionally increased water velocity, which corresponded with results from previous studies (Drapcho, 1993; Brown and Tucker, 2013). However, the slope of the regression line in this study (0.507) was lower than those reported in previous studies (0.622 for Drapcho, 1993; 0.604 for Brown and Tucker, 2013). The difference among the studies resulted from different head loss due to variations in shapes and sizes of water channels and ponds along with different circulator configurations.

The relationship between predicted and measured water flow rates is presented in Fig. 9. Predicted water flow rate was slightly lower than the measured water flow rate. However, satisfactory agreement was noted between measured and predicted water flow rates and the predicted values were 91.4% of the measured values.

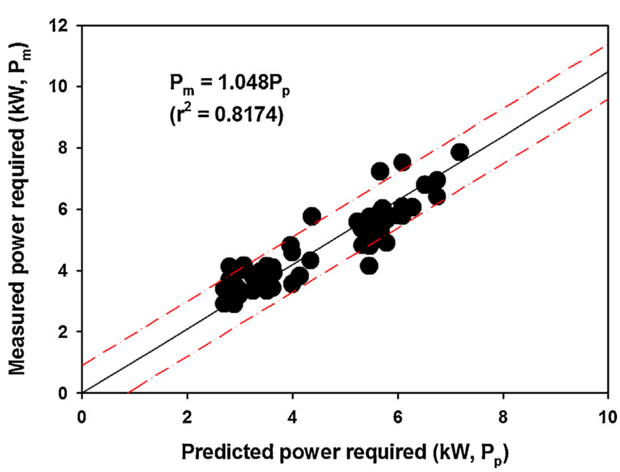

Fig. 6. Measured *vs.* predicted power requirements (the solid line: regression line, the dashed lines: prediction bands).

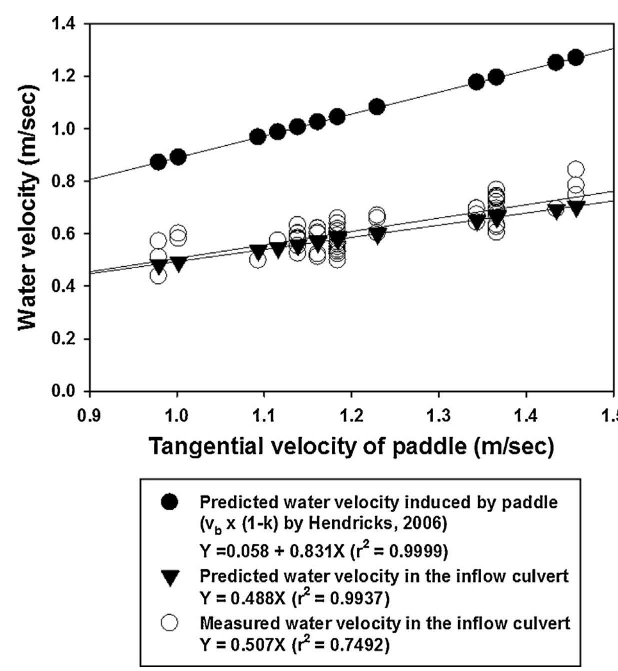

Fig. 8. Predicted and measured water velocities in the outflow and inflow culverts.

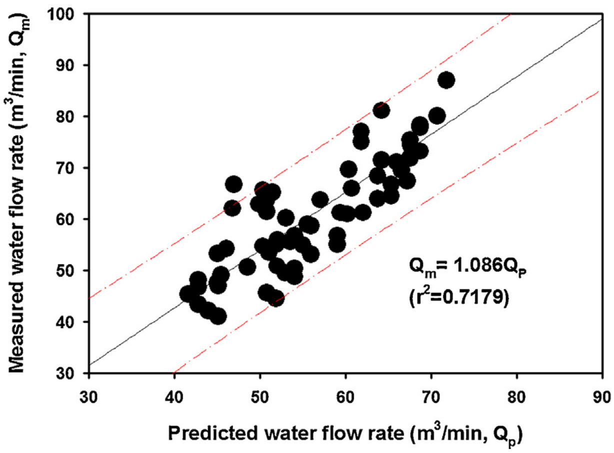

Fig. 9. Measured *vs.* predicted water flow rates (the solid line: regression line, the dashed lines: prediction bands).

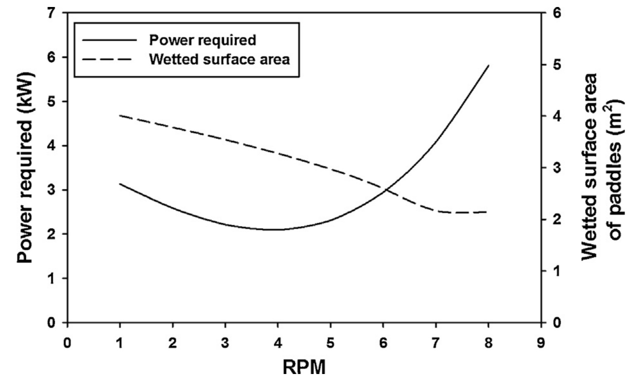

Fig. 10. Projected wetted surface area of the paddles and power required to pump a 50 m^3/min of water according to different paddle rotational speeds ($1 \leq RPM \leq 8$).

The models developed corresponded appropriately with actual values collected in the field and provided fundamental information for designing and retrofitting circulators for SPS. However, there are many unpredictable variables that can affect performance of circulators under field conditions. Wind was a critical factor that affected water flow rate and power required in the field. Also, small aquatic animals such as frogs and turtles, and dead fish pinned against the screens would have caused friction losses as well as sticks, grass clippings and other vegetation. As noted earlier, noticeable variations in the power requirement and water flow rate were observed even with similar operation conditions measured in the field. The power requirement should be determined conservatively to avoid selection of a suboptimal size or substandard motor. The failure to correctly size a motor could result in limited application of circulators and insufficient water flow rate. The importance of safe design and selection for circulators and motors was well addressed by Brown and Tucker (2013).

As the models reflected actual values appropriately, interpretation can be expanded over the measured ranges and some important considerations in designing paddlewheel type circulators for the SPS can be projected. Increasing paddle rotational speed increases power requirement drastically, although water flow rate does not increase proportionally with power consumption. High torque occurs with increasing rotational speed and causes a greater likelihood of mechanical failure. Increasing wetted surface area of paddles increases both water flow rates and power requirement linearly. Thus, increasing wetted surface area of paddles is more energy efficient than increasing rotation speed in order to achieve proper water flow rate and minimizes mechanical failure due to high torque. However, at the given pond water depth (around 1.5 m), it would not be practical to increase wetted surface area of paddles indefinitely. In order to increase wetted surface area at a limited pond water depth, paddles need to be wider, resulting in more weight on a longer shaft that would be withstand more severe tension and torsion. The material of paddles and supporting structures must be robust enough to overcome the considerable drag force applied on the wider paddles, which would require a greater capital investment. Design and construction of circulators in the SPS for catfish production should be conducted taking into account economic considerations.

At a certain threshold of the wetted surface area, the power requirement could increase as the attempt to decrease rotational speed is made to achieve a target water flow rate. For instance, in order to achieve a maximum target water flow rate of 50 m^3/min, various combinations between rotational speed and wetted surface area can be applied based on the models (Fig. 10). As noted in Fig. 9, power requirement follows a quadratic relationship ($1 \leq RPM \leq 8$) and increases with the rotational speed lower than 4 rpm as the wetted surface area increases accordingly. The minimum power requirement (or motor capacity) would be in the vicinity of 4 rpm and 3.5 m^2 of total wetted surface area. The drag force coefficient and slip factor that are determined by various shapes and features of paddles are also determinant design parameters. Thus, design should account for the combination of various factors along with paddle rotational speed to optimize performance of paddlewheel circulator for SPS.

Acknowledgments

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Appendix A. Appendix

No.	Operational parameter						Measured data					Predicted data		
	Pond size (ha)	Motor size (HP)	RPM	Rotation velocity (rad/s)	Tip velocity (m/s)	Water Depth (m)	Amperage I (A)	Power consumption, P_m (kW)	Water velocity, v_w (m/s)	Culvert wetted area, A_c (m^2)	Water flow, Q (m^3/min)	Power consumption ΣP_p (N m/s)	Power consumption P_{sum} (kW)	Water flow Q_c (m^3/min)
1	1.8	5	6.375	0.67	1.16	1.14	4.45	3.70	0.720	1.46	62.9	1033	2.80	49.8
2	1.8	5	6.500	0.68	1.18	0.97	3.89	3.23	0.638	1.22	46.8	896	2.80	42.8
3	1.8	5	6.500	0.68	1.18	1.17	4.33	3.60	0.567	1.49	50.8	1119	3.50	52.0

Appendix A (*Continued*)

No.	Operational parameter						Measured data					Predicted data		
	Pond size (ha)	Motor size (HP)	RPM	Rotation velocity (rad/s)	Tip velocity (m/s)	Water Depth (m)	Amperage I (A)	Power consumption, P_m (kW)	Water velocity, v_w (m/s)	Culvert wetted area, A_c (m^2)	Water flow, Q (m^3/min)	Power consumption ΣP_p (N m/s)	Power consumption P_{sum} (kW)	Water flow Q_c (m^3/min)
4	1.8	5	6.500	0.68	1.18	1.17	4.33	3.60	0.567	1.49	50.8	1119	3.50	52.0
5	1.8	5	6.750	0.71	1.23	1.09	4.12	3.43	0.657	1.39	54.7	1157	3.61	50.3
6	2.0	5	6.375	0.67	1.16	1.28	4.93	4.10	0.599	1.64	58.9	1158	3.62	55.5
7	2.0	5	6.500	0.68	1.18	1.14	4.66	3.87	0.522	1.46	45.6	1091	3.41	50.8
8	2.0	5	6.500	0.68	1.18	1.14	4.45	3.70	0.522	1.96	61.5	1091	3.41	50.8
9	2.0	5	6.500	0.68	1.18	1.17	4.55	3.78	0.498	1.49	44.5	1116	3.49	51.9
10	2.0	5	6.500	0.68	1.18	1.22	4.72	3.92	0.539	1.56	50.3	1165	3.64	54.0
11	2.1	5	6.250	0.65	1.14	1.19	4.21	3.50	0.701	1.52	63.8	1016	2.91	50.8
12	2.1	5	6.250	0.65	1.14	1.24	3.99	3.32	0.631	1.59	60.2	1063	2.89	53.0
13	2.1	5	6.250	0.65	1.14	1.26	4.69	3.90	0.577	1.61	55.6	1074	3.36	53.5
14	2.1	5	6.250	0.65	1.14	1.27	4.75	3.95	0.584	1.62	56.8	1084	3.39	54.0
15	2.1	5	6.375	0.67	1.16	1.18	3.89	3.23	0.721	1.51	65.2	1068	2.80	51.4
16	2.1	5	6.375	0.67	1.16	1.24	4.98	4.14	0.511	1.59	48.8	1125	3.52	54.0
17	2.2	5	6.375	0.67	1.16	1.42	5.79	4.81	0.603	1.82	66.0	1269	3.97	60.7
18	2.2	5	6.375	0.67	1.16	1.42	5.77	4.80	0.603	1.82	66.0	1269	3.97	60.7
19	2.2	5	6.500	0.68	1.18	1.02	3.84	3.19	0.608	1.29	47.0	955	2.99	45.1
20	2.2	5	6.500	0.68	1.18	1.17	4.28	3.56	0.617	1.49	55.1	1116	3.49	51.9
21	2.2	5	6.50	0.68	1.18	1.35	5.51	4.58	0.549	1.72	56.8	1279	4.00	59.1
22	2.2	5	6.50	0.68	1.18	1.35	4.27	3.55	0.549	1.67	55.1	1279	4.00	59.1
23	2.5	5	6.50	0.68	1.18	0.94	3.50	2.91	0.637	1.19	45.4	865	2.70	41.6
24	2.5	5	6.50	0.68	1.18	0.97	4.96	4.12	0.657	1.22	48.2	896	2.80	42.8
25	2.5	5	6.50	0.68	1.18	0.97	3.60	2.99	0.592	1.22	43.4	896	2.80	42.8
26	2.5	5	6.50	0.68	1.18	0.97	3.89	3.23	0.638	1.22	46.8	896	2.80	42.8
27	2.5	5	6.50	0.68	1.18	0.99	3.99	3.32	0.560	1.25	42.1	926	2.89	44.0
28	2.5	5	6.50	0.68	1.18	1.02	4.03	3.35	0.531	1.29	41.1	955	2.99	45.1
29	2.5	5	6.50	0.68	1.18	1.09	4.01	3.33	0.608	1.39	50.6	1039	3.25	48.5
30	2.5	5	6.50	0.68	1.18	1.09	4.01	3.33	0.608	1.39	50.6	1039	3.25	48.5
31	2.8	7.5	6.75	0.71	1.23	1.24	4.58	3.81	0.668	1.59	63.7	1323	4.14	57.0
32	2.8	7.5	7.38	0.77	1.34	1.24	6.44	5.35	0.642	1.59	61.2	1700	5.31	62.0
33	2.8	7.5	7.38	0.77	1.34	1.28	6.91	5.74	0.696	1.64	68.4	1750	5.47	63.7
34	2.8	7.5	7.38	0.77	1.34	1.28	5.77	4.80	0.696	1.53	64.0	1750	5.47	63.7
35	2.8	7.5	7.38	0.77	1.34	1.33	8.69	7.22	0.694	1.71	71.1	1813	5.67	66.0
36	2.8	7.5	7.38	0.77	1.34	1.35	7.23	6.01	0.672	1.72	69.5	1829	5.72	66.5
37	2.8	7.5	7.50	0.79	1.37	1.17	6.71	5.58	0.686	1.49	61.2	1675	5.23	59.4
38	2.8	7.5	7.50	0.79	1.37	1.19	5.79	4.81	0.766	1.52	69.7	1704	5.33	60.4
39	2.8	7.5	7.50	0.79	1.37	1.22	4.98	4.14	0.804	1.56	75.0	1748	5.46	61.8
40	2.8	7.5	7.50	0.79	1.37	1.22	6.01	5.00	0.825	1.56	77.0	1748	5.46	61.8
41	2.8	7.5	7.50	0.79	1.37	1.27	7.12	5.92	0.734	1.62	71.4	1818	5.68	64.2
42	2.8	7.5	7.50	0.79	1.37	1.27	6.38	5.30	0.833	1.62	81.1	1818	5.68	64.2
43	2.8	7.5	7.50	0.79	1.37	1.30	5.88	4.89	0.671	1.60	64.5	1852	5.79	65.3
44	2.8	7.5	7.50	0.79	1.37	1.35	6.96	5.79	0.719	1.72	74.4	1918	5.99	67.6
45	2.8	7.5	7.50	0.79	1.37	1.37	7.30	6.07	0.742	1.76	78.2	1949	6.09	68.7
46	2.8	7.5	7.50	0.79	1.37	1.37	6.95	5.78	0.695	1.76	73.2	1949	6.09	68.7
47	2.8	7.5	7.50	0.79	1.37	1.37	9.04	7.52	0.738	1.76	77.8	1949	6.09	68.7
48	2.8	7.5	7.50	0.79	1.37	1.42	7.28	6.05	0.733	1.82	80.1	2009	6.28	70.7
49	2.8	7.5	7.88	0.82	1.43	1.27	8.17	6.79	0.693	1.62	67.5	2086	6.52	67.2
50	2.8	7.5	8.00	0.84	1.46	1.26	7.70	6.40	0.783	1.61	75.4	2159	6.75	67.6
51	2.8	7.5	8.00	0.84	1.46	1.26	8.35	6.94	0.746	1.61	71.9	2159	6.75	67.6
52	2.8	7.5	8.00	0.84	1.46	1.35	9.44	7.85	0.842	1.72	87.1	2299	7.19	71.8
53	2.8	7.5	8.00	0.84	1.46	1.35	9.44	7.85	0.842	1.72	87.1	2299	7.19	71.8
54	3.0	7.5	6.75	0.71	1.23	1.32	6.92	5.75	0.601	1.69	61.0	1399	4.37	60.2
55	3.0	7.5	7.50	0.79	1.37	0.99	5.20	4.32	0.871	1.25	65.6	1389	4.34	50.3
56	3.0	7.5	7.50	0.79	1.37	1.22	6.40	5.32	0.825	1.56	77.0	1748	5.46	61.8
57	3.0	7.5	7.50	0.79	1.37	1.30	6.80	5.65	0.671	1.66	66.7	1852	5.79	65.3
58	4.4	5	5.38	0.56	0.98	1.22	4.57	3.80	0.510	1.56	47.6	677	3.25	45.1
59	4.4	5	5.38	0.56	0.98	1.22	4.09	3.40	0.570	1.56	53.2	677	2.70	45.1
60	4.4	5	5.38	0.56	0.98	1.27	3.61	3.00	0.637	1.62	62.1	704	2.80	46.8
61	4.4	5	5.50	0.58	1.00	1.22	3.49	2.90	0.581	1.56	54.2	723	2.89	46.1
62	4.4	5	5.50	0.58	1.00	1.24	4.21	3.50	0.700	1.59	66.7	738	2.80	46.9
63	4.4	5	6.00	0.63	1.09	1.30	5.00	4.16	0.498	1.66	49.5	983	3.07	52.9
64	4.5	5	6.13	0.64	1.12	1.22	4.81	4.00	0.573	1.56	53.5	984	3.07	51.0
65	4.5	5	6.25	0.65	1.14	1.22	4.57	3.80	0.599	1.56	55.9	1042	3.26	52.0
66	4.5	5	6.25	0.65	1.14	1.27	4.33	3.60	0.579	1.62	56.4	1084	3.39	54.0
67	4.5	5	6.25	0.65	1.14	1.30	4.72	3.92	0.553	1.66	55.0	1104	3.45	55.0
68	4.5	5	6.25	0.65	1.14	1.32	4.81	4.00	0.579	1.69	58.7	1124	3.51	55.9
69	4.5	5	6.25	0.65	1.14	1.32	4.01	3.33	0.524	1.69	53.1	1124	3.51	55.9
70	4.5	5	6.38	0.67	1.16	1.04	4.21	3.50	0.619	1.32	49.1	931	2.91	45.4
Max	4.5	7.5	8.00	0.84	1.46	1.42	9.44	7.85	0.87	1.96	87.05	2299.43	7.19	71.8
Min	1.8	5.0	5.38	0.56	0.98	0.94	3.49	2.90	0.50	1.19	41.05	676.78	2.70	41.6

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